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ROSAT POINTED OBSERVATIONS OF COOL MAGNETIC WHITE DWARFS

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ABSTRACT

Observational evidence for the existence of a chromosphere on the cool magnetic white dwarf GD 356 has been reported. In addition, there have been theoretical speculations that cool magnetic white dwarfs may be sources of coronal X-ray emission. This emission, if it exists, would be distinct from the two types of X-ray emission (deep photospheric and shocked wind) that have already been observed from hot white dwarfs. We have used the PSPC instrument on *ROSAT* to observe three of the most prominent DA white dwarf candidates for coronal X-ray emission: GD 356, KUV 2316+123, and GD 90. The data show no significant emission for these stars. The derived upper limits for the X-ray luminosities provide constraints for a revision of current theories of the generation of nonradiative energy in white dwarfs.

Subject headings: stars: coronae — white dwarfs — X-rays: stars

1. INTRODUCTION

White dwarfs have been known to be sources of X-ray emission since the detection of soft X-rays from the hydrogen-rich (DA) white dwarf Sirius B in 1975 (Mewe et al. 1975). Since then, the *Einstein* and *EXOSAT* Observatories have found X-ray emission from more than 30 relatively hot DA white dwarfs ($T_{\rm eff} \geq 25{,}000$ K) (e.g., Kahn et al. 1984; Pravdo et al. 1986; Petre, Shipman, & Canizares 1986; Paerels & Heise 1989), and many more have been detected with the *ROSAT* Observatory (e.g., Kidder et al. 1992; Barstow et al. 1993). In all cases but one (see below), the observed X-rays are not of coronal origin but are best explained as thermal emission from deep photospheric layers (e.g., Shipman 1976; Martin et al. 1982). If white dwarf coronal X-ray emission is to be identified, it must be from stars in which the X-ray optical depth is larger than unity in the photosphere so that the radiation produced in the deep photosphere is absorbed. This condition is met in helium-rich (DB) white dwarfs and those DA stars that have $T_{\rm eff} < 25{,}000$ K. However, Fontaine, Montmerle, & Michaud (1982) searched for coronal X-ray emission from hot DB dwarfs using *Einstein* and found none (see also Petre et al. 1986), and attempts to detect X-rays from nearby cool DA's have failed as well (e.g., Vaiana et al. 1981).

In the sole observed exception to the deep photospheric X-ray production mechanism, Fleming, Werner, & Barstow (1993) have recently reported the discovery of a "coronal" X-ray source around a very hot ($T_{\rm eff} = 1.2 \times 10^5$ K) DO white dwarf (KPD 0005−5106). The observed X-ray spectrum can be fitted by thermal bremsstrahlung from a $T = 2.6 \times 10^5$ K plasma surrounding the star. This plasma is presumed to be heated by shocks within a hot wind, in a process analogous to that in O and B stars. We note, however, that the temperature of the X-ray–emitting plasma in this case is well below typical coronal temperatures of 10^6–10^7 K. Further, this novel mechanism of X-ray emission is relevant only for very hot white dwarfs and cannot play any role in producing coronae around DA stars having $T_{\rm eff} < 25{,}000$ K. This letter is concerned with the existence of X-ray emission of truly coronal origin (i.e., from plasma at temperature $T > 10^6$ K), emission analagous to that from the hot coronae surrounding cool, late-type stars.

From a theoretical point of view, the lack of observed coronal emission from cool white dwarfs is unsatisfactory because the theory of wave generation in white dwarf convective zones predicts rather large acoustic fluxes, suggesting observable levels of coronal X-ray emission for DB white dwarfs with $T_{\rm eff}$ ranging from 20,000 to 35,000 K and DA's with $T_{\rm eff}$ in a narrow range about 10,000 K (Bohm & Cassinelli 1971; Arcoragi & Fontaine 1980; Musielak 1982, 1987).

To reconcile the theory with the X-ray observations, it has been suggested that most of the wave energy generated in white dwarf convective zones is either trapped (by wave reflection) or damped (by radiative damping) in the photospheres of these stars (Musielak & Fontenla 1989). Since both processes can be efficient in DA and DB stars, they may almost totally prevent transfer of wave energy from the region of wave generation to the outermost atmospheric layers, and thereby either prevent formation of coronae or at least limit coronal X-ray emission to nonobservable levels. However, for white dwarfs with surface magnetic fields above 10^5 G and convective motions in the surface layers, incompressible magnetohydrodynamic (MHD) waves can also be generated by convective flows "jiggling" the magnetic field lines. Since these waves do not suffer radiative damping, they are possible agents for carrying energy to the outer atmospheric layers (Musielak 1987). Therefore, among white dwarfs, cool magnetic stars appear to be the most promising candidates for the detection of coronal X-ray emission.

Furthermore, there is observational support for the expectation of detectable coronae in these stars. The cool magnetic white dwarf GD 356 ($T_{\rm eff} = 8 \times 10^3$ K; magnetic field strength $B = 1.5 \times 10^6$ G) shows resolved triplets of Hα and Hβ as emission lines (Greenstein & McCarthy 1985). There is no evidence for an interacting companion star; the data can be explained as emission from a thin layer of high-density ionized gas (i.e., a chromosphere). A corona would be a natural extension of this observed chromosphere.

The observational evidence of GD 356 and the theoretical suggestion that the most promising candidates for coronal X-ray emission are stars with convective zones and surface

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TABLE 1

PHYSICAL PARAMETERS OF SELECTED TARGET STARS

Name	WD Number	T_{eff} (10^3 K)	Magnetic Field (10^6 G)	Distance (pc)
GD 356	1639+537	8	15	18
KUV 2316+123 ...	2316+123	10.5	29	40
GD 90	0816+376	12	9	50

TABLE 2

EXPOSURE TIME AND UPPER LIMITS FOR SELECTED TARGETS

Name	Exposure Time (s)	Upper Limit (counts s^{-1})	Upper Limit (ergs s^{-1})
GD 356	4981 + 24402	1.8×10^{-3}	4.4×10^{26}
KUV 2316+123............	9488	2.8×10^{-3}	3.4×10^{27}
GD 90......................	8954	4.0×10^{-3}	7.8×10^{27}

magnetic field have led us to search for possible coronae around cool magnetic white dwarfs. If it exists, such emission would be distinct from the deep photospheric emission believed to be responsible for the soft X-rays detected from single DA white dwarfs having effective temperatures higher than 2.5×10^4 K (Shipman 1976) and distinct from the X-ray emission discovered by Fleming et al. (1993). In this Letter, we report on the analysis of *ROSAT* Position Sensitive Proportional Counter (PSPC) pointed observations of three cool magnetic DA white dwarfs (GD 356, KUV 2316+123, and GD 90) selected as the most promising candidates for observable coronal emission (see § 2). Analysis of the data finds no significant X-ray emission for any of these stars (see § 3). The deep observations allow us to set significant upper limits on this emission, and these limits appear to require a revision of current theories of the generation of nonradiative energy in white dwarfs.

2. SELECTION OF TARGET STARS

The most promising white dwarfs for the detection of coronal X-ray emission are those having convective zones and observational evidence for surface magnetic fields. It is now well established that most DA stars with $T_{eff} < 18{,}000$ K have convective zones (e.g., Bohm 1970; Fontaine 1973). In addition, there are almost 30 presently known (primarily DA) white dwarfs with measured magnetic fields of order 10^6 G or stronger (Angel 1978; Angel, Borra, & Landstreet 1981; Schmidt 1989). From the list of magnetic white dwarfs given by Schmidt (1989), we selected 14 DA stars whose effective temperatures implied the existence of vigorous convection and whose proximity suggested that their coronae, if they existed, should be observable. Over the course of several observing cycles, we were granted observing time for four of our highest priority candidates. The observation of one of the four, EG 250, was unfortunately interrupted before it reached any significant length. However, deep observations were carried out at the locations of three DA stars. These were, in addition to the obvious choice of GD 356, the stars KUV 2316+123 and GD 90 (see Table 1). The distances in Table 1 were obtained as follows. For GD 356, the value of McCook & Sion (1987), based on parallax measurements, was used. For GD 90, parallax was not available, so the distance was determined by fitting the absolute visual magnitude to the multichannel color index $G-R$, according to Greenstein (1976a, b). For KUV 2316+123, neither parallax nor the $G-R$ index was available, so we calculated the $G-R$ index from the relationship between the $G-R$ and $B-V$ indices and used this value to estimate the distance.

3. ANALYSIS AND RESULTS

The exposure times for the PSPC observations of the three target stars are given in Table 2. Note that GD 356 was observed on two occasions. The data were processed by the *ROSAT* Standard Analysis software. In each case, the detection algorithms failed to find a statistically significant source at the target star's position. However, since these were deep observations, we were able to derive useful upper limits to the X-ray fluxes from these stars, using the PROS analysis package.

Figure 1 (Plate L4) shows a *ROSAT* 0.1–2.4 keV image centered on the position of GD 356. The data are from the longer of the two observations made of this star. In deriving upper limits to the flux from each target, we used a circle 1!5 in radius centered on the target position as the "source" region. A concentric annulus having inner and outer radii of 1!5 and 2!5 was used to define the background. Circles at 1!5 and 2!5 are drawn in Figure 1. An ideal background region would be further removed from the source, to exclude more possible source photons in the tail of the point-spread function. However, in practice we found that for each of our targets, larger annuli yielded higher, not lower, background counts, presumably owing to the presence of nearby sources.

The upper limit we assign to the detector count rate for each target (Table 2) corresponds to the 99.73% confidence interval (i.e., 3 σ) for the "source" flux, as determined using Bayesian statistics. In each of our observations there is a *slight* excess of counts in the source region over that expected from the background. However, in all cases, this amounts to fewer than 10 net source counts, in backgrounds ranging from several tens of counts to over a hundred counts. This situation, few or no source counts in a nonnegligible background, is appropriate to the use of Bayesian statistics rather than the classical approach (Kraft, Burrows, & Nousek 1991). We carried out this analysis using a source code obtained from E. Schlegel, who had modified the original code of Kraft et al. (see Schlegel & Petre 1993).

The PIMMS software package was used to convert the upper limits on detector count rates to upper limits on L_X, the stars' luminosities in the PSPC 0.1–2.4 keV bandwidth. The calculation used a thermal bremsstrahlung emission model and an assumed temperature $T = 2.5 \times 10^6$ K. The resulting fluxes are fairly sensitive to the temperature assumed. For example, using a coronal temperature of 5×10^6 K gives an increase of $\approx 40\%$ in the fluxes for a given count rate. To estimate hydrogen column densities for the absorption calculation, we used the data of Fruscione et al. (1994), who give hydrogen column density measurements for 842 stars. Since our targets are nearby, we considered only the entries to their table lying within 100 pc. From these, we used the entries having the least separation in R.A. and declination from our targets to estimate N_H pc^{-1} in the direction of our targets. The resulting column densities for our targets are less than 10^{19}. Note that the upper limit derived for GD 356 is the result of summing "source" and "background" counts obtained in both observations of that star.

In summary, analysis of the X-ray data obtained during

ROSAT PSPC pointed observations of three cool magnetic white dwarfs (GD 356, KUV 2316+123, and GD 90) has failed to identify any of the stars as a source of coronal X-ray emission. In view of the theoretical predictions for large acoustic and MHD wave energy fluxes in these stars, the lack of observable coronae is a puzzle. This is especially so in the case of GD 356, where there is the reported observational evidence for a chromosphere. These results provide significant constraints for theories of the generation of nonradiative energy in white dwarfs.

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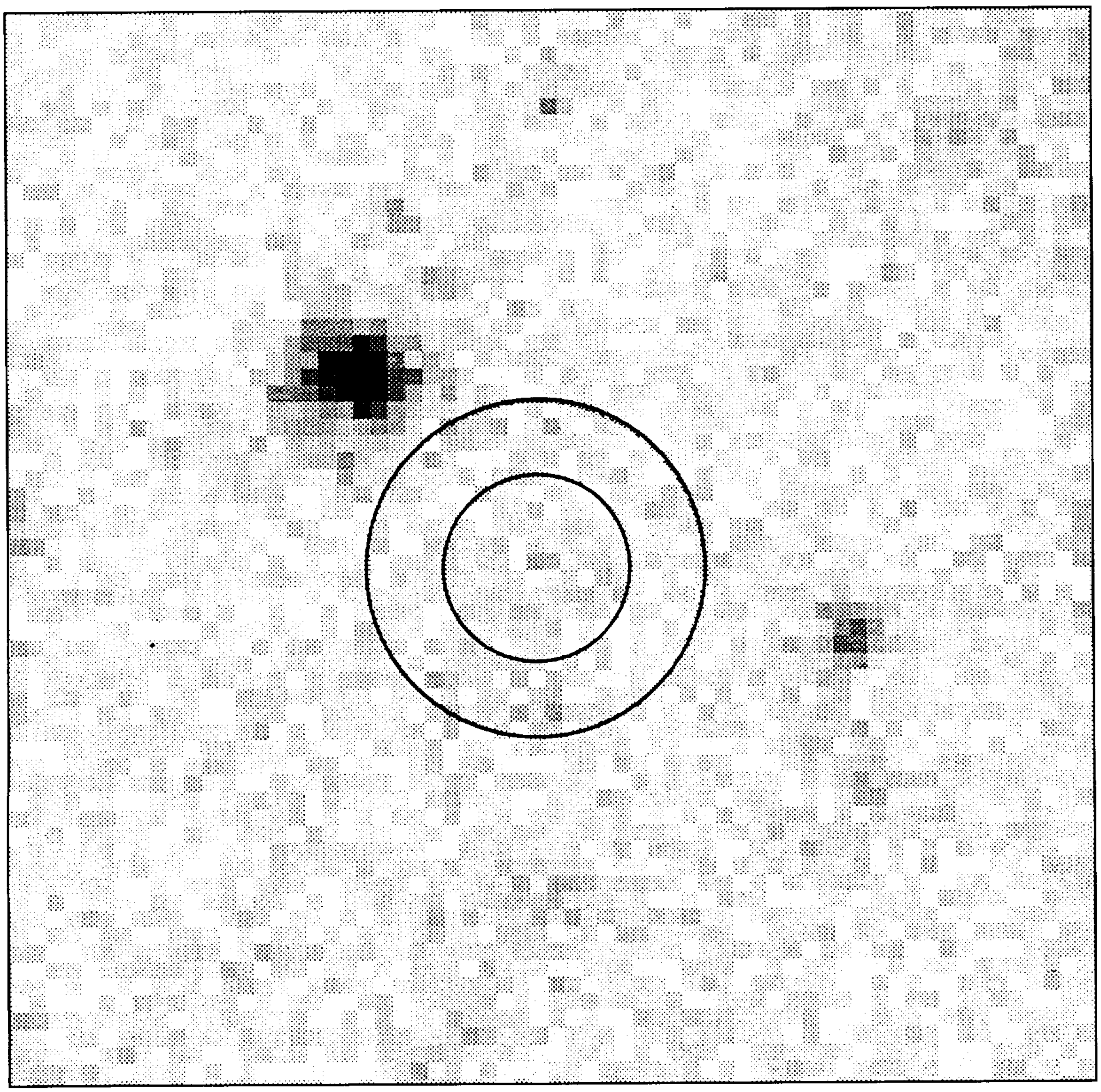

FIG. 1.—Gray-scale representation of the central part of the PSPC image from the 24 ks exposure of GD 356. Circles with radii of 1'.5 and 2'.5 centered on the position of GD 356 define the source region and the background annulus used in deriving upper limits to the 0.1–2.4 keV count rate.